Prof. Gisbert Glasmachers

GMSK

The Modulation Used For Mobile Communications

Modern communications technology must be matched by modern electronics. So that the precious resource of frequency space is not wasted, new types of modulation are being tested and brought into use; the article below introduces the GMSK type of modulation currently in use for GSM mobile telephones.

1. Introduction

In many branches of technology, a change from analogue to digital techniques is taking place. Current examples of this are video technology and telephony. Modern equipment transmits and stores what were originally analogue signals in digitised form. To this can be added continuously increasing transmission via wireless paths.

Radio technology must provide facilities for the transmission of digital signals. One elementary problem here is the restriction of the bandwidth. Analogue signals, rather like human speech, encounter a natural band width restriction at approximately 10 kHz. Consequently, the medium wave radio transmitters, with analogue amplitude modulation, require precisely this bandwidth. Digital signals, due to their fast rise times, require a much higher bandwidth. If then (to stay with the example of human speech), we digitise at a high resolution, e.g. 12 bits, the bandwidth required for a transmission could easily be increased to several MHz. It is clear that technology is trying everything in order to reduce this unbearable drain on precious frequency space. The main aim of this article is to introduce GMSK, the preferred type of modulation for radio transmission. To this end, the state of the art is described, together with the options for the radio amateur wishing to become familiar with this technology using simple resources.

2. Type of modulation

The type of modulation is usually determined by the efficiency, security and costs of the transmission path. A basic distinction is made between amplitude modulation and phase modulation. Amplitude modulation in the field of long wave and medium wave radio has been known since the nineteen-twenties. Its susceptibility to interference makes it largely unsuitable for modern communi-

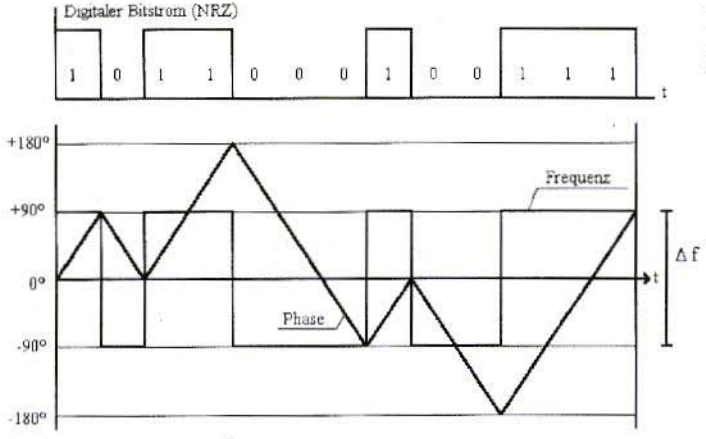


Fig 1: Digital signal Showing the Effect on Frequency and Phase

cations systems.

Phase modulation affects the frequency and phase of a carrier. With digital frequency modulation, the frequency must be switched over in sympathy with the data signal, see Fig. 1.

There is a direct relationship between the frequency and the phase. If the frequency goes up, the phase rises linearly. It is clear that a big frequency change, Δf, is easier to detect in the receiver than a small one. But unfortunately the spectrum width of a radio signal is directly proportional to the size of the frequency change. A reasonable compromise must therefore be found between the frequency shift, Δf, and consideration of the restricted width of the radio channel. At a low received field strength, the channel width plays an important part, yet the noise output increases linearly with the bandwidth. For this reason it is also desirable that the channel width should be as small as possible.

Examples of the effects of the type of modulation on the spectrum are shown in Fig. 2. The frequency axis is divided up into 4 transmission channels. The ideal spectrum would be a uniform distribution of the output over the channel width. In addition, propagation into the adjacent channel would be prevented completely. Such ideal conditions can not be provided in practice. Two real spectra are also shown, GMSK in channel 3 which can still be described as good; MSK in channel 2, by contrast, is not good. The frequency shift keying shown in Fig. 1 corresponds to MSK.

From the spectrum point of view, the bandwidth of an MSK signal is unnecessarily large, we can attempt to reduce it using suitable filtration. Filtration after modulation would be possible, so that we could simply cut off the edges of the

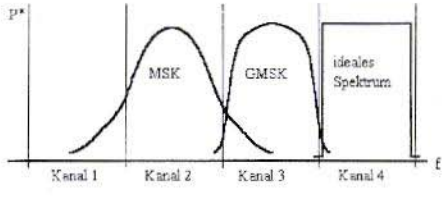


Fig 2: Examples of Frequency Spectrum

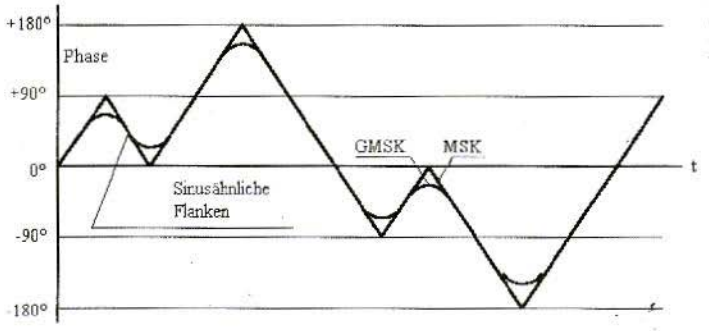


Fig 3: Transition from MSK to GMSK by Rounding Corners

spectrum using a band pass filter. This would also mean that the information itself was also cut off. It seems more sensible to filter the digital signal before modulation, which leads directly to the GMSK spectrum. The concept is known as Gauss Minimum Shift Keying. It includes filtration using a Gauss filter. The results are shown in Fig. 3.

The corners in the phase gradient widen the spectrum. If they are rounded off, the spectrum becomes narrower. We can vary how distinctly the rounding off is made, this is characterised by the so-called BT product, where

B = Bandwidth of Gauss filter
T = TBIT, the bit time.

For MSK, BT approaches infinity. Frequently used values for BT are 1, 0.5 and 0.3. It should be pointed out that the European mobile radio systems (GSM) are operated using GMSK modulation with BT = 0.3.

3. Generation of GMSK signals

Basically, any phase modulation and this includes GMSK can be obtained by changing the phase or frequency. A simple method of generating frequency-modulated signals consists of using a voltage-controlled oscillator (VCO). The frequency is changed using a control voltage fed in from outside the control loop. This produces only an approximate adjustment of the frequency shift.

A precise adjustment, as required for MSK and GMSK, requires the phase to undergo a modulation instead of the frequency. For this, we generally use quadrature modulators, the functional principle is shown in Fig. 4.

The function of this modulator is to generate a carrier with any phase displacement desired at constant amplitude. For this purpose, the carrier is divided into two signals, one with zero degrees phase (sin) and one with 90 degrees phase (cos). These two signals are generated by producing a carrier at twice the frequency, followed by a 2:1 frequency divider and an inverter. The two signals can be set to any amplitude between +1 and 1 by means of a multiplier (mixer). Finally, the two signals are brought back together. The multipliers are controlled by the digital data which is divided into two signals (I and Q) and shaped through digital filters. This produces a phase transitions of 90 degrees, as shown in Fig. 5.

In practice quadrature modulators are on

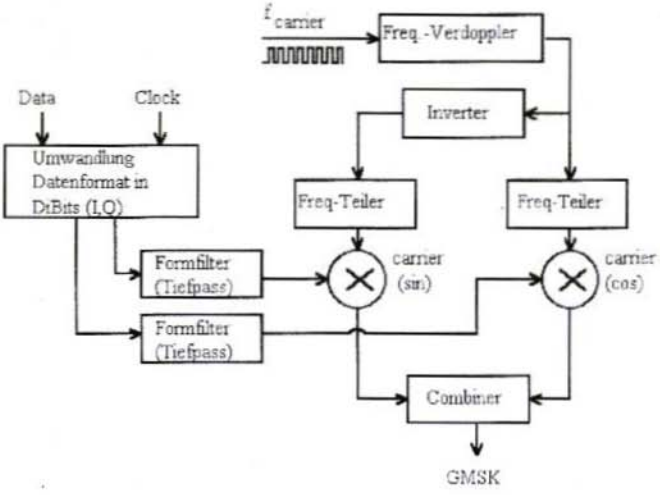


Fig 4:Block Diagram of a Quadrature Modulator

Freq. - Verdoppler = Frequency Doubler

Freq. - Teiler = Frequency Divider

Unwandlung Datenformat in DiBits (IQ) = Convert data to I Q format

sale as complete circuits, e.g. from HARRIS, MAXIM, TEMIC and many others. Splitting the digital signal up into I and Q components and filtering it is usually left up to the electronics manufacturer. This can be achieved by using a micro-controller, for example one from the MICROCHIP PIC range, which reads off the necessary I and Q components from a table. The filtration required for GMSK can also be incorporated into the tables without any problem. For this purpose at least one up to a maximum of three past and future bits

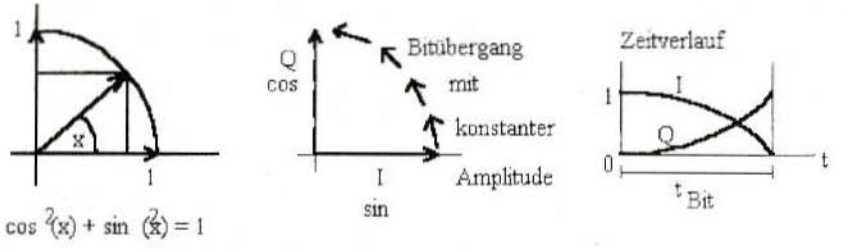


Fig 5 : Combination of sine and cosine components

Bitubergang mit konstanter amplitube = Bit transition with constant amplitude

Zeitvertauf = Time period

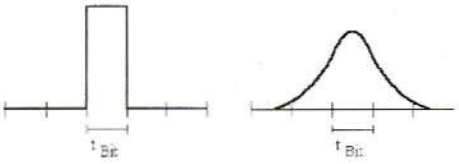


Fig 6: Effect of Gauss Filter on a "One Bit"

around the current bit must be examined; see Fig. 6.

The filtered bit extends into the adjacent bits, this is referred to as symbolic interference if adjacent bits interfere with one another. The lower the limiting frequency of the filter, the wider (and flatter) the bit becomes. This means that the phase rotation, which should be precisely 90 degrees per bit, changes depending on the bits immediately in front and behind. The exact phase rotation can be calculated mathematically. If we takeas an approximation that the change extends to only a single bit, we obtain 8 variants in all, which are shown in Fig. 7.

If the consideration extends over plus/minus two bits, this gives a total of 32 different phase gradients. These must each be calculated for the I and Q components in four possible quadrants (from 0 to 360 degrees). At least 10 measurements must be provided per bit, this would require the preparation of 2560 storage locations. This number can be considerably reduced by skilful use of symmetries. The phase jumps arising from the quantisation can be sufficiently dampened through simple RC filters. Integrated circuits for the conversion from digital signals to the I-Q signals, e.g. the CMX 589 are available from the British manufacturer CML.

4. Demodulation

There are various demodulation techniques. We can distinguish between:

1) Frequency demodulation
2) Quadrature demodulation
   - Coherent
   - Non-coherent

In all cases, an uncorrupted bit flow must be available at the demodulator

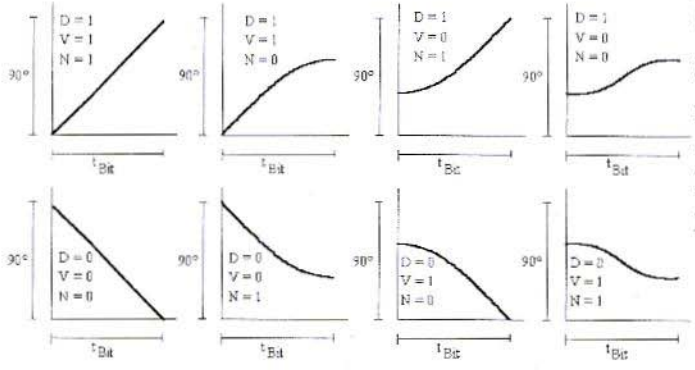


Fig 7: Phase Change by Filter For a Single Bit Approximation Giving 8 Variants.

D = Data Bit

V = Previous Data Bit

N = Next Data Bit

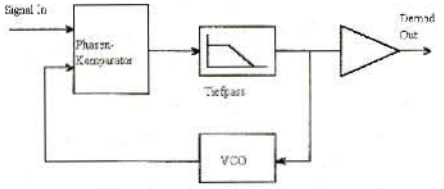


Fig 8: PLL as an FM Demodulator

output. Because the functioning is simpler, frequency demodulation will be discussed first.

4.1. Frequency demodulation

As can be seen from Fig. 1, for MSK the frequency gives a direct reflection of the bit flow. Thus an elementary FM demodulator is sufficient, with either a tuned circuit or a PLL [1]. Technical problems arise from the frequency shift, which in some circumstances is small, this leads to relatively low voltages at the discriminator. Attempting to increase the sensitivity of the discriminator results in a narrower frequency range. This causes the negative effects of drift and component ageing to become noticeable. Similar findings apply for the PLL, with the tuned circuit of the VCO operating as a discriminator. A basic circuit diagram for the functioning of a PLL as an FM demodulator is shown in Fig. 8.

Both circuits basically operate using oscillation circuits, which cause transient effects when the frequency changes suddenly, as happens with MSK. This gives a problem finding out the optimal damping while maintaining a sufficiently high limiting frequency. With the PLL, its structure as a control circuit adds a further difficulty, with the low-pass filter having a considerable influence on the frequency response. GMSK, with its smoother frequency transitions, does not make such high demands on the frequency response of the discriminator, yet it is more difficult to retrieve data securely using this type of modulation.

4.2. Coherent quadrature demodulation

The principle of quadrature mixture can also be used for the reverse transformation of the modulated signal into the base band. The output signal in this case is a rotating voltage vector, the direction of rotation contains the digital information; see Fig. 9.

In order for the demodulation to precisely reproduce the base band, the local oscillator must be twice the frequency of the transmission signal, due to the subsequent halving of the frequency, and coherent with the input signal. In order to achieve this, it must be derived from the input signal in some way. Various processes for achieving this are known, which are known as carrier recovery.

One is taken from television engineering: the unmodulated carrier frequency,

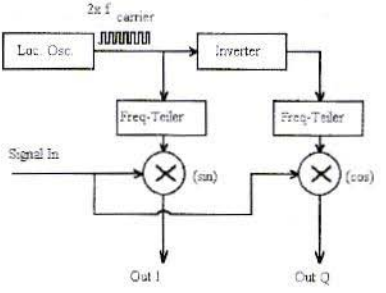


Fig 9: Quadrature Demodulator

the so-called synchronisation burst, is transmitted for a specific time. The local oscillator is synchronised to this frequency and retains it in the subsequent phase, in which modulated signals are transmitted. Thus the carrier and the data signals alternate in the transmission signal (Fig. 10). A disadvantage here is the time lost for the synchronisation; the effective bit rate falls. There are complete circuits available for this demodulation process, such as the above-mentioned CMX 589. The greater the time interval between the synchronisation burts, the more the frequency will be displaced from the coherent condition in the subsequent data phase.

Another option for generating a coherent carrier consists in the obtaining of a phase-locked signal from the phase-modulated signal. For hard phase shift keying e.g. QPSK - the carrier can be obtained by means of double squaring of the phase-modulated signal [2]. This procedure does not work with soft phase shift keying such as MSK and GMSK. Here special control circuits are needed (Costas loop), but because of their time constants these react slowly [3]. Consequently, the effective bit rate is reduced for these systems as well.

4.3. Non-coherent quadrature demodulation

If the local oscillator oscillates freely, a precise conversion will not occur. Even if precise quartz oscillators are used either on the transmitter side or in the local oscillator of the receiver, a residual error remains,

$$\Delta f = f_{sender} - f_{Loc.Osc.}$$

In this case, we speak of non-coherent demodulation. We can only try to keep this error as small as possible. The I and

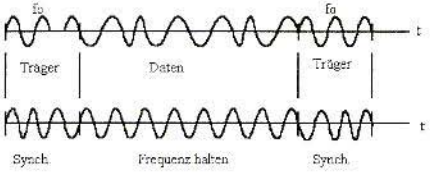


Fig 10 : Synchronisation of the Local Oscillator

Tager = Carrier, Daten = Data, Frequenz halten = Frequency Held

Q outputs of the demodulator produce an output, even when no modulation is present on the input signal. But such a system can be used as a serviceable demodulator. Various cases are possible here:

1) The resulting output (modulation plus frequency error) rotates in varying directions, depending on the value of the data bit. This condition occurs if

$$\Delta f \lhd 4 f_{Bit} = \frac{4}{T_{Bit}} ist$$

At high bit rates, or for high-precision oscillators, this condition is easy to maintain. The value of a bit can then be recognised directly from the direction of rotation of the output.

2) The resulting output rotates in only one direction. The speed of rotation is merely reduced or increased by the value of the bit. It then becomes more difficult to recognise the bit. The processor employed for recognition must measure the actual speeds of rotation and read out the data from their difference. More recent developments take up this idea and attempt demodulation

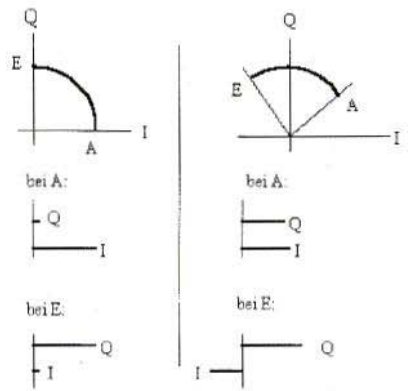


Fig 11: Examples of phase changes
A = Start of Bit, E = End of Bit

directly on the intermediate frequency, using very rapid analogue/digital converters and correspondingly fast processors. This avoids frequency conversion into the base band with the associated additional circuitry.

To sum up, it can be stated that non-coherent demodulation gives the best efficiency with regard to the effective bit rate. A burst is not necessary for synchronisation. Moreover, little circuitry is needed. There are no tuning processes, such as are almost unavoidable with tuned circuits.

5. Decoding

The I and Q voltages produced by the demodulator are still purely analogue signals. They must be reconverted into digital signals. This task (data reconstruction) is undertaken by the decoder. First, the I and Q signals produced by coherent demodulation must be examined. The phase transition for a logic one corresponds (for MSK) to a rotation through +90 degrees; see Fig. 11 above.

Even in coherent demodulation, the phase of the local oscillator, as against the phase of the reception signal, is not defined, the angular gradient of a bit can lie anywhere on the circle with radius 1. Fig. 11 shows two possible cases for this.

5.1. Analysis of direction of rotation of phase

In order to analyse the direction of rotation of the phase without using extensive technology,a sampling rate which corresponds precisely to the bit frequency is sufficient in principle. This means that the I and Q components are measured at the output of the demodulator at the beginning (A in Fig. 11) and at the end (E) of the bit. The second measurement (E) is then simultaneously the initial measurement for the next bit. The direction of rotation is particularly easy to recognise if the output unambiguously changes the quadrant: see Fig. 11 on right. The associated direction of rotation is determined from the difference between two successive measurements, as can be seen from Table 1 (see Fig. 11 on left and right).

Table 1 can easily be extended to cover the entire phase circuit and both directions of rotation. In systems created in practise, more than two measurements must take place, because it is not so easy to determine exactly when a bit begins. Having several measurement points also creates the advantage that the noise can be suppressed a little by forming a mean value. The comparison operations listed in the table can be carried out using simple micro-controllers. These can also regenerate the cycle; see below.

The analysis of the direction of rotation

Message	I and Q (left of fig 11)	I and Q (right of fig 11)
A	I(A) > 0, Q(A) = 0	I(A) > 0, Q(A) > 0
B	I(B) = 0, Q(B) > 0	I(B) < 0, Q(B) > 0
Quadrant Changes	Not defined	Yes
Check	I(B) < I(A), Q(B) > Q(A)	N/A
Direction	Left	Left
Bit	One	One

Table 1: Determining Direction of Rotation

described above leads to satisfactory results for the coherent demodulation of MSK signals. In order to arrive at the case of the demodulation of GMSK with a non-coherent local oscillator, the procedure can be extended as follows:

- Establishment of differential frequency
- Re-transformation from GMSK to MSK

The differential frequency can be measured accurately only if there is no modulation, or for a known bit sample. Otherwise, it is subjected to drift, which is mainly conditioned by temperature. Additional problems arise from the phase noise of the oscillators. If we look at it from this viewpoint, we can recommend data transmission in blocks using a prefixed synchronising burst.

But this is not essential: provided that the frequency error is small in relation to the bit rate, we can dispense completely with any correction of the frequency error. Taking the frequency error into account requires the calculation of the absolute phase angle for each measurement. This is mathematically possible, with some effort, but it can be done faster using tables (although unfortunately a lot of memory space is needed). But if the determination of the direction of rotation has to be corrected again, with the help of the frequency offset, simple micro-controllers rapidly become overloaded here. All that can be done then is to use programmable logic circuits (FPGAs). This increases the price and the amount of programming considerably.

For GMSK signals, the phase angle change per bit is often considerably less than 90 degrees; see Figs. 3 and 7. It is obvious that this makes satisfactory recognition of the direction of rotation more difficult. Since the GMSK signal on the transmitter side has emerged from an MSK signal via Gauss filtration, the filtration can be reversed again by carrying out the inverse operation on the receiver side The more samples per bit are captured, the better this succeeds. The digital filter required for this can be programmed in a sufficiently rapid processor.

The simple recognition of the direction of rotation referred to above requires only low expenditure. It functions with a low bit error rate right down to BT = 0.3. A pre-condition is that there must always be a stable local oscillator with low phase noise. For the radio amateur interested in practicable solutions, there are thus several variants open:

- FM demodulation at lowest possible intermediate frequency;
- Coherent demodulation with integrated circuits, using a synchronous burst;
- DIY non-coherent demodulation.

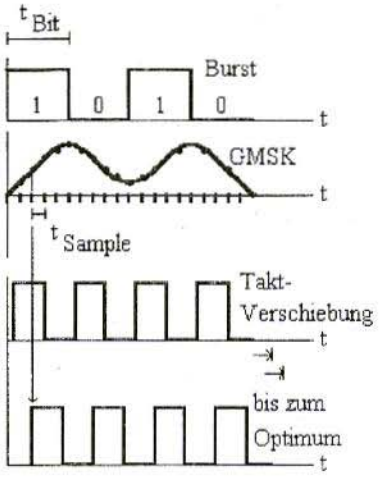


Fig 12: Burst of 4 Bits With 5 Samples.

Takt Verschiebung = Cycle displacement, bis zum optimum = to the optimum

5.2. Obtaining the Clock

Serial bit flows generally require a clock, the edges of which should, if possible, lie in the centre of the bit. It is the task of the decoder to generate this clock. A pre-condition is a bit rate which is maintained quartz-accurately on the transmitter side and which is known on the receiver side. It is also recommended that the signal should be scanned on the receiver side using a whole-number multiple of the bit rate, for example with 5 or 10 samples per bit. In this way, there are always several measurement points in a bit. If, using ten-fold sampling, we now generate the clock edge with the fifth sample, then the edge will be positioned correctly in the centre of the bit time. The only question still to be answered is how to recognise the beginning of a bit. The following alternatives are available here:

- The beginning of a bit is recognised by the change in the direction of rotation
- The beginning of each bit is defined by synchronisation with the help of a synchronous burst.

The change in the direction of rotation takes place each time there is a change from zero to one or vice versa. If we acquire this moment, we can synchronise the cycle to it. But at the actual start of the data transmission no real change is present. The very first cycle is thus not so easy to recognise. In addition, with GMSK specifically, this change is also sharpened: see Fig. 3.

A synchronous burst at the beginning of the block transmission is available as a remedy. This consists of a precisely defined one-zero-one- ...etc. sequence. The smoothing should be deactivated during the burst. The clock is generated by a quartz oscillator, the frequency of which is precisely matched to the data frequency. However, its phase shift relative to the data bits is undefined. With a suitable delay, the phase can be brought into the optimal position, i.e. in the centre of the bit. The decoder must generate this delay. The synchronous burst at the beginning of a transmission block serves, among other things, to pick out the optimal delay time. This is then retained, unchanged by the subsequent data transmission, see Fig 12.

The clock is not used until the first actual data bit is encountered. Since it is generated with quartz accuracy, it will be accurate for the subsequent bits. In this way, several hundred, or several thousand, bits can be transmitted without post synchronisation.

6. Summary

The transmission of digital signals through radio channels using GMSK modulation will achieve greater and greater penetration over wide areas. Even progressively orientated radio amateurs can become involved in this field. The present report is intended to provide some background knowledge, together with a certain amount of orientation to assist in practical implementation.

7. Literature

[1] Best, Roland; Theory and application of phase-locked loop, AT-Verlag, Stuttgart

[2] Glasmachers, Gisbert; Digital phase modulation; VHF Reports 2/1999

[3] Mäusl, Rudolf; Digital modulation procedures; Hüthig-Verlag, Heidelberg

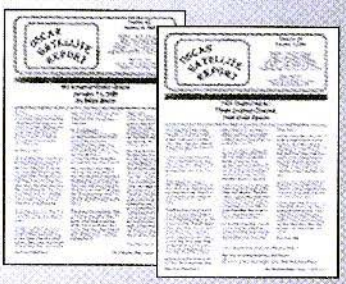
Amateur Television Quarterly

Great articles on :
ATV
BALLOONING
PROJECTS
SSTV
ATV ACTIVITIES

VISA
M/C
AMEX

OSCAR Satellite Report

A great NEWSLETTER published twice a month to keep you up to date on what is happening. Sent FIRST CLASS MAIL!



Write or check webpage TODAY for more information!

Published by Harlan Technologies
5931 Alma Dr., Rockford, Illinois 61108 USA
http://www.hampubs.com